6-2019

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Abstract

Thoracic surgery via video assisted thoracoscopic surgery (VATS) began in the early 1990s, as a minimally invasive alternative to open thoracotomy for performing lobectomies, wedge resections, and segmentectomies. It initially showed improved morbidity and mortality, decreased pain, and decreased length of stay when compared to traditional open thoracotomy (Zhang & Gao, 2015). To its detriment, VATS has a steep learning curve and manipulation of instruments has been described as non-intuitive. The video camera used provides a two-dimensional image, with limited depth perception compared to the naked eye in an open procedure. Due to these shortcomings, and in spite of its superiority in terms of measurable patient outcomes, VATS has been slow to acquire traction and the majority of thoracic surgeries are still performed via the open approach (Kent et al., 2014).

Robot assisted thoracoscopic surgery (RATS) was approved by the FDA for human use in 2001, and has seen rapid growth, especially in the United States in the last decade. Like VATS, it offers better patient outcomes, decreased complications, shorter length of stay and decreased pain. It also provides the practioner certain advantages: wristed instrument movement, stereoscopic three-dimensional view, and physiologic tremor control (Tchouta et al., 2017). These advances theoretically replicate the ease of performing thoracic surgery via open approach while conferring the improved outcomes of a VATS procedure to the patient.

The main drawback of RATS is its prohibitive cost. The hospital must first acquire the multi-million-dollar robot platform itself and pay an annual maintenance and education fee, which is in itself tens of thousands of dollars per year. Additionally, the instruments used for

robotic surgery are sold as single use, disposable items, which cost nearly two thousand dollars themselves to perform a lobectomy or resection (Kajiwara et al., 2018).

Recent studies attempted to understand the financial impact of robotic thoracic surgery, both in the settings of national health care schemes (Kajiwara et al., 2018), and at individual surgical centers (Novellis et al., 2018). Robotic thoracic surgery may, in fact be performed without incurring a debt on each case performed, but only if each robotic platform is used hundreds of times per year, at high volume centers with experienced and efficient operators and staff. Though many alternatives to the da Vinci platform, the prototypical robotic surgery platform, are still in their nascent stages and few have seen clinical use, competition may also serve to control costs (Peters, Armijo, Krause, Choudhury, & Oleynikov, 2018).

The studies included in this review showed a clear advantage for both RATS and VATS over the open approach in terms of clinical outcomes, equivocal superiority in oncological outcomes for RATS, and a higher cost for both the patient and institution for robotic surgery compared to either alternative. Future research in this area needs to include large scale randomized trials, similar to those showing the superiority of robotic surgery for prostatectomies over the open approach. Only then can the utility of RATS be truly shown to be worth the cost.

Introduction

The purpose of this literature review is to ascertain the value and benefits of robotic assisted thoracoscopic surgery (RATS) when compared to the more traditional approaches, video-assisted thoracoscopic surgery (VATS) and the open surgical approach. As there are no existing randomized clinical trials comparing the efficacy of RATS to other approaches, retrospective studies were chosen. These studies were broadly categorized into five groups.

The first group of retrospective studies consisted of database reviews examining safety, efficacy, and cost. Safety and efficacy were measured by metrics including peri-operative complications, surgical length, and length of stay, while cost was measured by cost to the individual in certain studies, and cost to the institution in others. The second group of retrospective studies added oncological efficacy to database driven retrospective studies. Oncological efficacy was measured via the incidence of nodal upstaging, the presence of unsuspected pathological hilar or mediastinal disease found during pathologic study of surgical specimens.

The third group of retrospective studies described in this literature review analyzed outcomes and cost, but from the perspective of a single surgical center or single surgeon. These studies were included to better capture the purported improvements made to an institution's thoracic surgery program after the introduction of robotic surgery. The fourth group of studies analyzed in this review are meta-analyses of existing reviews. The final group of studies are purely financial analyses of the feasibility and cost of robotic surgery, and the number of surgeries needed to be performed annually in order to avoid incurring debt.

The efficacy, safety, and cost of robotic surgery should be of great importance to anesthesia providers. Robotic surgery promises a number of purported advantages, primarily for the operator, but comes with a significant cost, both in money for the platform and equipment, and in time due to longer cases and protracted room turnovers. As robotic platforms become more prevalent, anesthetists, especially senior anesthetists with steering power for institutions, will need to become more familiar with the technologies and their value propositions. It is imperative that anesthesia remain part of the conversation as robotic surgery is determined to be either an investment in the future of surgery, or an unnecessary expenditure that could be better spent elsewhere.

These studies present numerous limitations that need be mentioned. Due to their retrospective nature, and a complete lack of randomized clinical trials, the highest level of evidence any of the included studies can provide is IV. The retrospective studies based on large databases primarily acquired their data based on ICD-9 codes, but a code specific for robotic surgery was not introduced until 2007, so there is a potential that cases performed as RATS were coded as being VATS or open. The database driven studies also analyze inpatient data only and provide limited insight into patient morbidity and mortality following surgery. The studies that do analyze long-term survival were rarely able to follow a patient for the intended duration. Selection bias is often a concern and is difficult to account for in retrospective studies. The concern being that surgeons opt to use the open approach over the less invasive methods for larger, more extensive tumors, making a true comparison between the open and other approaches less objective.

Literature Review

Retrospective Cohort Studies Based on Database Reviews Examining Safety, Efficacy, and Cost

A total of five studies were chosen for this literature review that were published in the last five years and with data collected from large databases, allowing the creation of retrospective cohort studies. These databases allowed the authors to compare multiple outcomes of interest for robotic assisted thoracic surgery compared to video assisted and open thoracic surgery.

Some of the outcomes of interest were the need for blood transfusion, respiratory or cardiac complications, operating room time, length of stay, morbidity and mortality, and in some of the studies, cost. Of the five retrospective database studies reviewed, the studies performed by Kent, et al., Oh et al., and Paul et al. are included below as these studies have the larger sample sizes and perform propensity matching based on Elixhauser or similar comorbidity scores.

Open, Video-Assisted Thoracic Surgery, and Robotic Lobectomy: Review of a National Database. (Kent et al., 2014)

This study created by Kent et al. set about to compare the in-hospital mortality and overall complication rates for pulmonary resection when performed either as an open procedure, via video assisted thoracoscopic surgery (VATS), or robotic assisted thoracoscopic surgery (RATS). A retrospective database study using the State Inpatient Databases (SID) with propensity-matching was completed (Kent et al., 2014), giving this study a level of evidence of IV.

Demographic information was collected for each patient, and an Elixhauser comorbidity index, a metric created to measure the effect of comorbidities on length of stay, hospital charges, and in hospital mortality, was used to assess the severity of each patient's comorbidities. A propensity-matched analysis was also performed based on demographics, comorbidities, and hospital settings in a 1(RATS) to 3 (VATS or open) ratio, due to the much larger sample in the latter group (Kent et al., 2014).

33,095 patients were identified as having undergone lobectomy or segmentectomy between 2008 and 2010. 430 were performed via RATS, 12,427 via VATS, and 20,238 via an open procedure. In the unmatched analysis RATS resections had lower mortality (0.2 vs 1.1 vs

2.5%; *p* =.0001) and median length of stay (4 vs 5 vs 6days; *p* = .003) compared to both VATS and open resections (Kent et al., 2014).

Table 4. Propensity-Matched Analysis of Patients Undergoing Open, Video-Assisted Thoracic Surgery (VATS) or Robotic Pulmonary Resection

Outcome	Open (n = 1,233)	VATS (n = 1,233)	Robotic (n = 411)	*p* Value[a]	*p* Value[b]
Mortality	25 (2.0%)	14 (1.1%)	1 (0.2%)	0.122	0.016
LOS (mean)	8.2	6.3	5.9	0.454	<0.0001
Routine discharge	734 (59.5%)	795 (64.5%)	262 (63.7%)	0.828	0.214
Prolonged LOS	118 (9.6%)	85 (6.9%)	18 (4.4%)	0.118	0.003
Any complication	667 (54.1%)	558 (45.3%)	180 (43.8%)	0.674	0.003
Bleeding complication	24 (1.9%)	16 (1.3%)	7 (1.7%)	0.633	0.795

[a] Between robot and VATS resections. [b] Between robot and open resections.

LOS = length of stay; VATS = video-assisted thoracic surgery.

Table 1. (Kent et al., 2014, table 1)

In the propensity-matched analysis, when compared to open procedures, RATS resections had lower mortality (0.2 vs 2%, *p* = 0.016), length of stay (5.9 vs 8.2 days, *p* < 0.0001), and complication rates (43.8 vs 54.1%, *p* = 0.003). Compared to VATS resections, RATS had lower mortality rates (0.2 vs 1.1% *p* = 0.12), length of stay (5.9 vs 6.3 days, *p* = 0.45), and complication rates (43.8 vs 45.3%, *p* = 0.68), though none to the point of statistical significance (Kent et al., 2014).

A second analysis was performed, comparing outcomes when performed by surgeons who perform more than 20 RATS resections per year. Amongst this select group, RATS resections showed improved mortality against both open resections (0 vs 1.9%, *p* = 0.011) and VATS resections (0 vs 1.6%, *P* = 0.02). In this group, RATS resections also had a favorable length of stay (5.9 vs 7.4 days, *P* = 0.015) and overall complication rate (42.9% vs. 53.0%, *P* = 0.008) compared to open resections (Kent et al., 2014).

The final analysis looked only at the results of "robotic" surgeons, those who performed RATS resections in addition to VATS and open procedures. This showed a significant reduction in mortality (2.6% vs 0.3%, *p* = 0.003), complication rate (43.4% vs 50.6%, *p* = 0.036), and prolonged length of stay (4.6% vs 9.9%, *p* = 0.036) when compared to open resections. This comparison also showed a non-significant decrease in mortality (0.3 vs 1.2%, *p* = 0.062), length of stay (6 vs 6.4 days, *p* = 0.454), and prolonged length of stay (4.6 vs 7.6%, *p* = 0.055) when comparing RATS to VATS resections. This analysis was not propensity-matched due to the smaller sample size (Kent et al., 2014).

Robotic Assisted, Video Assisted Thoracoscopic and Open Lobectomy: Propensity Matched Analysis of Recent Premier Data (Oh, Reddy, Gorrepati, Mehendale, & Reed, 2017).

Oh and company performed this study to retrospectively analyze and compare the clinical outcomes for elective robotic lobectomies, video assisted lobectomies, and open lobectomies, in this article referred to as RL, VL, and OL respectively. The Premier database was used to perform a propensity-matched cohort analysis, giving this study a level of evidence of IV. The data for this study was gathered for cases between 2011 and 2015, the researchers hope being that at this time many of the surgeons will be past the initial learning curve for robotic surgery, and outcomes more descriptive of experienced robotic surgeons (Oh, Reddy, Gorrepati, Mehendale, & Reed, 2017).

Patient data collected were demographics and type of cancer, hospital characteristics, region, and perioperative outcomes. Complications were categorized as intraoperative, perioperative (from completion of surgery to discharge), or 30 days post-operative, and an Elixhauser comorbidity index was used to categorize comorbidities based on ICD-9 codes (Oh, Reddy, Gorrepati, Mehendale, & Reed, 2017).

In order to mitigate potential selection bias, propensity matching was performed to create two comparative groups, RL vs OL, and RL vs VL. Covariates used for matching were patient demographics including type of malignancy, Elixhauser comorbidity score, hospital characteristics, type of hospital (academic or community), and location (urban or rural) (Oh, Reddy, Gorrepati, Mehendale, & Reed, 2017).

23,779 elective lobectomies were included in the study, 2,994 of which were performed with robotic assistance. 2,775 (92.7%) of the robotic cases were matched to OL cases, and 2,951 (98.6%) were matched to VL cases. When compared to OL, RL had longer mean operating room time of 40 minutes, similar intraoperative complication rates (3.4% versus 2.6%, $P = 0.1343$), lower postoperative complication rates (34.6% vs 43.2%, $P < 0.0001$), and lower 30-day postoperative complication rates (37.8% vs 45.8%, $P < 0.0001$). RL patients were more likely to be discharged home than to a transitional care facility (92.2% vs 88.0%, $P < 0.0001$), and mortality both post-op and 30-days post-op were lower (1.0% vs 1.7%, $P = 0.0282$, and 1.3% vs 2.2%, $P = 0.0108$, respectively). RL also showed a lower complication rate than OL, including blood transfusions (3.4% versus 4.7%, $P = 0.0139$ for intraoperative; 3.8% versus 5.4%, $P = 0.0032$ for postoperative), respiratory failure (8.0% versus 9.8%, $P = 0.0267$), pneumonia (6.0% versus 9.4%, $P < 0.0001$), need for mechanical ventilation (5.4% versus 8.2%, $P < 0.0001$), atrial arrhythmias (10.9% versus 13.6%), and wound complications (0.7% vs 1.7%, $P = 0.0012$) (Oh, Reddy, Gorrepati, Mehendale, & Reed, 2017).

When compared to VL, the findings for RL were still favorable, but to a lesser degree. Operating room time was longer for RL by 28 minutes. Mortality rates, both postoperative and 30-day were similar between both groups. Intraoperative complication rates were similar for RL and VL (3.2% vs 3.1%, $P = 0.9406$), but RL had better postoperative and 30-day complication rates (34.1% vs 37.6%, $P = 0.0061$, and 37.3% vs 40.5, $P = 0.0130$, respectively) and mean length of stay (6.9 vs 7.3days $P = <0.0060$). Conversion to open was less likely in the RL group (6.3% vs 13.1%, $P <0.0001$), and RL patients were more likely to be discharged home (92.7% vs

90.9, *P* = 0.0108). Complication rates were similar for RL and VL, with the exception of myocardial infarctions (0.3 vs 0.8%, *P* = 0.0307) and postoperative bleeding (4.4% vs 9.3%, *P*<0.0001), though postoperative transfusions were similar (Oh, Reddy, Gorrepati, Mehendale, & Reed, 2017).

Table 5. Summary of Clinical Outcomes, Matched Analysis (1:1)

Variables	RL (n = 2,775)	OL (n = 2,775)	*p* Value RL Versus OL	RL (n = 2,951)	VL (n = 2,951)	*p* Value RL Versus VL
OR time, minutes	275.5 ± 94.6	235.3 ± 93.5	<0.0001	275.1 ± 93.9	247.6 ± 86.8	<0.0001
Conversion to open	179 (6.5)	NA		187 (6.3)	387 (13.1)	<0.0001
Complications						
Intraoperative[a]	93 (3.4)	73 (2.6)	0.1343	94 (3.2)	92 (3.1)	0.9406
Postoperative[b]	961 (34.6)	1,198 (43.2)	<0.0001	1,007 (34.1)	1,109 (37.6)	0.0061
Index hospital[c]	1,000 (36.0)	1,220 (44.0)	<0.0001	1,047 (35.5)	1,142 (38.7)	0.0113
Thirty-day	1,048 (37.8)	1,272 (45.8)	<0.0001	1,101 (37.3)	1,195 (40.5)	0.0130
Index hospital LOS, days	7.0 ± 5.7	8.9 ± 5.9	<0.0001	6.9 ± 5.5	7.3 ± 7.5	0.0060
Median, days	5	7		5	6	
Discharge status						
Health facility	188 (6.8)	284 (10.2)	<0.0001	190 (6.4)	234 (7.9)	0.0302
Home	2,559 (92.2)	2,442 (88.0)	<0.0001	2,734 (92.7)	2,679 (90.9)	0.0108
Mortality[d]						
Index hospital	28 (1.0)	48 (1.7)	0.0282	27 (0.9)	34 (1.2)	0.4400
Thirty-day	36 (1.3)	62 (2.2)	0.0108	35 (1.2)	40 (1.4)	0.6420

[a] Intraoperative complications included intraoperative bleeding and iatrogenic injuries. [b] Postoperative complications included all complications occurring after surgery through discharge. [c] Index hospital complications included all complications that occurred from admission to discharge. [d] Mortality rate was measured from admission to discharge ("Index hospital") and admission to 30 days ("30-day").

Values are mean ± SD or n (%).

LOS = length of stay; NA = not applicable; OL = open lobectomy; OR = operating room; RL = robotic-assisted lobectomy; VATS = video-assisted thoracic surgery; VL = VATS lobectomy.

Table 2. (Oh et al., 2017, table 2)

Comparative Effectiveness of Robotic-Assisted vs Thoracoscopic Lobectomy (Paul et al., 2014)

This study was created to ascertain the safety and efficacy of lobectomies performed via robotic-assisted thoracic surgery (RATS) by comparing them to the same surgery performed via video-assisted thoracoscopic surgery (VATS). As no large randomized trials have been attempted, due to constraints of cost and the large sample size that would be required, a retrospective study was performed.

The Nationwide Inpatient Sample (NIS) database harbors nearly 20% of data from hospital discharges of all-payer inpatient care for the United States. Adult patients who had undergone lobectomies via either RATS or VATS were identified by their ICD-9 codes for the years 2008 through 2011, as the ICD-9 code for robotic-assisted surgery was only introduced in 2007 (Paul et al., 2014). As a retrospective cohort analysis, it provides Level IV evidence.

The outcomes of interest were in-hospital mortality, complications, and a composite outcome of in-hospital mortality and myocardial infarction (MI) and/or stroke, identified via ICD-9 codes. Patients were categorized demographically and by the pre-existing conditions of coronary artery disease (CAD), heart failure, chronic pulmonary disease, hypertension, chronic kidney disease, diabetes, and peripheral vascular disease, and an Elixhauser comorbidity score was generated for each patient. Hospitals were categorized by region, size, urban vs rural location, and teaching vs non-teaching status (Paul et al., 2014).

Between 2008 and 2011, 2,498 RATS lobectomies and 37,595 VATS lobectomies were performed and identified. In-hospital mortality was similar between RATS and VATS lobectomies (0.7% vs 1.3%, $P=0.15$), as was length of stay (5 days vs 5 days), strokes (1.6 vs 1.4%, $P = 0.89$), and pulmonary complications (33.9% vs 31.8% $P = .29$). Patients undergoing RATS lobectomies did more poorly than those undergoing VATS when comparing overall complication rates (50.1% vs 45.2%, $P = .032$), and iatrogenic complications (5% vs 2% $P = 0.003$). RATS patients were less likely to be discharged directly home (60.8% vs 70.3% $P < 0.001$) requiring discharge to a facility before going home. Finally, robotic surgery incurred a larger total median charge ($79,375 vs $54,695, $P < 0.001$) and estimated total cost ($22,582 vs $17,874, $P < 0.001$) (Paul et al., 2014).

Retrospective Cohort Studies Based on Database Reviews Examining Oncological Efficacy and Long-Term Survival

Two studies were reviewed that followed the model of database-driven retrospective cohort studies detailed in the previous section, with the additional metrics of oncological efficacy and long-term survival.

Comparison of Video-Assisted Thoracoscopic Surgery and Robotic Approaches for Clinical Stage I and Stage II Non-Small Cell Lung Cancer Using the Society of Thoracic Surgeons Database (Louie et al., 2016)

This study sought to compare the morbidity, 30-day mortality, and oncological efficacy, as measured by nodal upstaging, between robotic (RL) and video assisted (VATS) lobectomies. Nodal upstaging is the presence of unsuspected pathological hilar (pN1) or mediastinal (pN2) disease found during pathologic study of surgical specimens and is used as a quality metric for the completeness of surgical nodal dissection. As the relative safety, and morbidity and mortality rates have been shown to be similar between RL and VATS in previous studies, an additional outcome of interest was related to early-stage non-small cell lung cancer (NSCLC). A retrospective study with data collected from the Society of Thoracic Surgeons General Thoracic Surgery (STS- GTS) database was performed (Louie et al., 2016), providing a level of evidence of IV.

Data was collected from the years 2009 through 2013, searching for primary lobectomies for Stage I or II NSCLC. The outcomes of interest were classified as: operating room time, length of stay, operative morbidity, 30-day mortality, and hilar nodal upstaging (cN0 to pN1). In addition to the standard demographics, data regarding tumor clinical stage and size, laterality and location of said tumor, preoperative staging method, and smoking status (never vs ever) were collected (Louie et al., 2016).

A total of 1,220 robotic lobectomies and 12,378 VATS lobectomies were identified as meeting the standards set by the researchers. A propensity-matched study was not performed due to time and cost constraints for the statistician involved, but the two groups were shown to be similar. Right sided cT1a or cT1b tumors, more often in the upper lobe, were the majority found in both groups (Louie et al., 2016).

Consistent with other studies comparing RL and VATS, median operative time was longer for RL (186 vs 173 minutes), and all other operative metrics and complication rates were similar between the two groups. The exception being that fewer RL cases returned to the operating room for bleeding (14.8% vs 29.6%, $p = 0.35$). Patients having RL were more likely to be discharged sooner (IQR 2-5 days vs 3-6 days $P<0.001$), and less likely to have stays greater than 7 days (16.9% vs 20.3%). In hospital mortality was similar between RL and VATS (0.3% vs 0.6% $P = 0.18$), as was 30-day mortality (0.6% vs 0.8%, $P = 0.42$) (Louie et al., 2016).

Nodal upstaging was determined to be similar between both methods (RL 8.44% vs VATS 7.95%) and was similarly more likely with more advanced staging in both methods, though neither approach showed superiority (Louie et al., 2016).

Table 4. Pathologic Nodal Upstaging Overall and Stratified by Clinical Staging

	Proportion of Cases Upstaged to pN1 (Number Upstaged/Total Cases [%])			
Clinical Stage	Overall	Robotic Treatment	VATS	*p* Value
cT1aN0	322/5,412 (5.95)	29/471 (6.16)	293/4,941 (5.93)	0.8422
cT1bN0	257/3,008 (8.54)	19/293 (6.48)	238/2,715 (8.77)	0.1844
cT2aN0	254/2,307 (11.01)	34/244 (13.93)	220/2,063 (10.66)	0.1228
cT2bN0	69/546 (12.64)	7/47 (14.89)	62/499 (12.42)	0.6263
Total	902/11,273 (8.00)	89/1,055 (8.44)	813/10,218 (7.96)	0.5847

VATS = video-assisted thoracoscopic surgery.

Table 3. (Louie et al., 2016, table 3)

Long-term survival based on the surgical approach to lobectomy for clinical stage I nonsmall cell lung cancer: comparison of robotic, video-assisted thoracic surgery, and thoracotomy lobectomy (Yang et al., 2017)

This study compares the differences in perioperative complications, long-term overall survival (OS), and disease-free survival (DFS), of lobectomies when performed as an open approach, via VATS or RATS. A propensity-matched retrospective cohort study was performed, giving this article a level of evidence of IV (Yang et al., 2017).

Adult patients were selected for having had a diagnosis of Stage I Non-Small Cell Lung Cancer (NSCLC), having undergone a lobectomy via open procedure, RATS, or VATS, without having received preoperative radiation or chemotherapy between the years of 2002 and 2012. Other exclusionary criteria were: concurrent malignant disease, other primary cancers, small cell lung cancer, and having received other procedures in addition to the lobectomy (Yang et al., 2017).

Survival and presence of disease following surgery was ascertained using records of surveillance and treatment visits. As there is concern that patients with worse disease or tumor burden, may be selected for open surgery rather than RATS or VATS, a propensity matched analysis was performed. Patients were categorized demographically, and by clinical variables including smoking history, clinical cancer stage, and pulmonary function test results. Overall survival (OS) was defined as death from any cause, and disease-free survival (DFS) was defined as recurrence, or death (Yang et al., 2017).

Before matching, a total of 2132 cases met the inclusion criteria, 184 RATS, 761 VATS, and 1187 open lobectomies. Amongst this unmatched group, worse survival was seen for open lobectomies compared to RATS lobectomies, but without significant difference between RATS and VATS (Yang et al., 2017).

Propensity-score matching selected 470 unique patients. Surgical complications were similar between all three groups, with a shorter length of stay seen for both minimally invasive groups (RATS and VATS). Patients undergoing RATS lobectomies did have a higher number of lymph nodes stations sampled than the VATS or open groups (5 vs 3 vs 4, $P<0.001$), nodal upstaging was slightly higher in the RATS groups, but not to a significant degree (Yang et al., 2017).

There was no significant difference in overall survival (OS) between the three groups (RATS 77.6%, VATS 73.5%, Open 77.9%). The main predictors for longer OS were younger age, not smoking, lower clinical stage, better pulmonary function, and well differentiated tumors. Following a univariate analysis, RATS showed to have longer disease-free survival (DFS) than VATS or open lobectomies (5-year DFS 72.7% vs 69% vs 65.5%, $P = 0.34$ and 0.047), though when a multivariate analysis was performed, accounting for patient and disease conditions, no significant difference was found. The main predictors for longer DFS were younger age, non-smoker, well differentiated tumors, and better preoperative pulmonary function (Yang et al., 2017).

Retrospective Reviews Examining Safety, Efficacy, and Cost from a Single Surgeon's or Surgical Practice's Experience

A total of four articles were reviewed that analyzed the outcomes of different approaches for thoracic surgery from the point of view of a single surgeon or surgical practice. This sub-type of retrospective analysis was included in this review for two reasons. The first is to provide increased granularity, as greater detail could be collected as the researchers had direct access to individual patient's charts. The second is to allow and account for improvements over time, as a practioner becomes familiar with the equipment, and to observe for improvements in outcomes. The two studies detailed below were selected due to their longer duration, larger sample size, and in the case of the second study, cost analysis.

Robotic Versus Thoracoscopic Resection for Lung Cancer: Early Results of a New Robotic Program (Mungo et al., 2016)

This research article was created by thoracic surgeons from Johns Hopkins in Baltimore and Memorial Sloan-Kettering in New York. Their goal was to assess the surgical outcomes of a thoracic surgery group, proficient in VATS lobectomies and segmentectomies, when transitioning to robotic video assisted thoracoscopic surgery (shortened to RVATS in this article) for performing the same procedures (Mungo et al., 2016). As a retrospective study, this article provides a level of evidence of IV.

The study collects patient information from December 2007 through May 2014, with the introduction of RVATS beginning in 2011. Patient information was collected from the Johns Hopkins Cancer Registry (JHCR). Data collected for patients included standard demographics, tumor characteristics, including size, histology, and stage. Pre-operative disease conditions and pulmonary function test results were collected. Intra-operative outcomes of interest were the similar to other studies: number of lymph nodes resected, conversion to open thoracotomy rate, days spent in ICU, days with a chest tube, and total length of stay. Post-operative complications were also identified. Patients were excluded from the study if they were less than 18 years old, had pre-operative chemotherapy or radiation, had any resection other than segmentectomy or lobectomy, or required a sleeve resection (Mungo et al., 2016).

A total of 133 patients met the inclusion criteria, 80 of whom underwent surgery via VATS, the other 53 via RVATS. The two groups were similar in terms of pre-operative demographics, with higher FEV1 scores and more never-smokers in the VATS group. The RVATS group had a lower conversion rate (13% vs 26% $P = 0.25$), however the author points out that the conversion rate for VATS greatly dropped over the course of the study, suggesting a learning curve for VATS in the early years of the study. RVATS yielded a higher median lymph node dissection than VATS (9 vs 7, $P = .049$). There were no deaths in either group, and morbidity and complications of all types were equally low for both groups. Length of stay was similar between both groups (Mungo et al., 2016).

Robotic Surgery, Video-Assisted Thoracic Surgery, and Open Surgery for Early Stage Lung Cancer: Comparison of Costs and Outcomes at a Single Institute (Novellis et al., 2018)

The third study analyzing the outcomes and costs of robotic surgery for lobectomies when compared to traditional open and VATS approaches at a single center, was published in February of 2018, and performed by a group of thoracic surgeons at a single center in Milan, Italy (Novellis et al., 2018). As a retrospective study, a level of evidence of IV is provided.

Unique to this study, one surgeon was given the option to perform lobectomies or segmentectomies via RATS , VATS, or an open procedure. The other three thoracic surgeons in the group could choose between open or VATS approach. Data was collected on a consecutive series of 103 patients undergoing surgery for stage I or II NSCLC between May 2015 to March 2016. Operating room times, length of stay, adverse events, and costs were recorded and analyzed for each patient (Novellis et al., 2018).

23 patients had surgery via RATS, 42 via VATS, and 38 via open approach. The patient characteristics for age, ASA score, FEV1, and comorbidities were similar between all three

groups with the exception of tumor size. Patients undergoing open approach had a larger median tumor than RATS or VATS approaches (3cm vs 2.1cm vs 2.2cm, $P = .025$). Complication rates were similar between each group. Unlike other studies, RATS was shown to be shorter in duration than VATS, but both were longer than open surgery (150 vs 191 vs 116 minutes, $P < 0.001$). Consistent with other studies, a greater mean number of lymph node stations were removed under RATS than VATS or open (4.7 vs 2.7 vs 3.7, $P < 0.001$), and mean length of stay was shown to be shorter for RATS than VATS or open (4.1 Vs. 6.6 vs 7.9, $P = 0.053$) (Novellis et al., 2018).

The Italian Public Health System reimbursement for lobectomy is €11,500 per patient. This does not include any additional reimbursement for the price of equipment. Though patients undergoing RATS lobectomies did have shorter lengths of stay, the money saved did not make up for the additional costs incurred from consumables unique to the robotic platform, valued at €2,062, and depreciation of the robot platform itself, €532 per case. The cost of robotic surgery was still less than the total reimbursement, €9441.50 (82.1%) compared to 68.6% and 67.6% for open and VATS approaches, so the hospital was still able to generate a profit from performing a RATS lobectomy (Novellis et al., 2018).

Selection bias may be present, as it was seen that patients undergoing open approaches had larger tumors, suggesting open approach was used for more extensive tumors. Of the four surgeons in the study, only one performed RATS approaches, so the efficacy of the approach may be conflated by this specific surgeon's skill, though the authors insist that all four of the surgeons were highly proficient in the techniques they employed (Novellis et al., 2018).

Meta-Analysis of Existing Retrospective Studies

Two meta-analyses were included in the literature review, both are included here as one explicitly compares RATS to VATS, and the other RATS to the open approach.

The Use of Robotic-Assisted Thoracic Surgery for Lung Resection: A Comprehensive Systematic Review (Agzarian et al., 2016)

This meta-analysis of existing articles was created to systematically evaluate the clinical and cost effectiveness of RATS when compared to VATS and open thoracotomy for lung resection, by categorizing the outcomes into four outcome areas of interest: technical, perioperative, oncological, and cost (Agzarian et al., 2016). As a review of existing retrospective studies, this article is given a level of evidence of IV.

A comprehensive search of MedLine and EMBASE databases was completed between 2014 and 2015, finding studies comparing RATS and VATS and open approach as well as isolated case studies on RATS, and evaluating both 3 and 4 port techniques. Studies were excluded if the RATS cases analyzed numbered less than 20, if robotic surgery was only used as a hybrid procedure, or if no resection was actually performed. In the end a total of 20 studies were deemed appropriate for this meta-analysis (Agzarian et al., 2016).

Technical outcomes were broken down into operative time and need to convert to open thoracotomy. Operative time was shown to be longer with RATS than VATS or open approaches in 12 out of 13 studies, with mean operative time of 190.08 minutes (range: 100-241 minutes). The mean operative time was 61.69 minutes longer for RATS when compared to open approach, and 64.28 minutes longer when compared to VATS (Agzarian et al., 2016). Of the 11 studies reviewing the rate of conversion to open procedure, the mean conversion rate was 7.9% (range 2.9-19.2%) (Agzarian et al., 2016).

Perioperative outcomes were broken down into incidence of prolonged air leak (PAL) and chest tube drainage, blood loss, pain, and length of stay. PAL occurred at a mean rate of 14.38% with no significant difference between RATS and VATS, but a lower incidence of PAL when comparing RATS to open was seen in 2 studies. No significant difference was seen in chest tube duration between any approach. There was a significant decrease in blood loss between RATS and open approaches, but no significant difference between RATS and VATS. Only one study conducted a comparison of pain between approaches, showing that patients undergoing RATS had significantly lower pain scores after 3 weeks when comparing patients undergoing open thoracotomy for the same surgery. Length of stay was 1.97 days shorter for RATS when compared to open approach but showed no significant difference when compared to VATS (Agzarian et al., 2016).

Oncological outcomes were categorized into number of lymph nodes (LN) dissected, nodal upstaging, and survival. Two studies were included that analyzed the median number of LN stations dissected, and neither showed a difference between RATS or open approaches. The one study comparing RATS to VATS did show a higher rate of nodal upstaging (15.2% vs 13.2%, $P = 0.72$). Multiple studies showed that RATS approaches had low (0-.5%) 30- and 90-day mortality rates. The overall survival rate was 80%, with 91% for stage IA, 88% for stage IB, and 49% for stage II. One study showed a one-year recurrence rate of 13.2% with 2-year survival at 87.6% and disease-free survival at 70.2%. When compared to VATS, one study showed a decreased 30-day mortality for RATS (0.9 vs 0%, $P < 0.0001$) though all other studies showed no significant difference (Agzarian et al., 2016).

When comparing the costs between RATS and open thoracotomy, two of the three studies showed a higher cost for RATS approach ($22,582 vs $17,874, $P \leq 0.001$), while the other study showed a lower cost for RATS approach ($8368 vs $4380) related to increased length of stay following open thoracotomy. Four studies compared cost of RATS to VATS procedures and RATS was shown to be consistently more expensive, between $3182-4565 per case. This increased cost is due primarily to disposable instruments (Agzarian et al., 2016).

Robot-assisted Thoracic Surgery Versus Open Thoracic Surgery for Lung Cancer: a System Review and Meta-Analysis (Zhang & Gao, 2015)

The second meta-analysis focused on morbidity and mortality rates for surgical treatment of lung cancer, comparing RATS to open thoracic surgery (OTS) (Zhang & Gao, 2015). As a meta-analysis of existing retrospective studies, this article has a level of evidence of IV.

A systematic search of PubMed and ScienceDirect was performed, searching for retrospective case-control, cohort based, or randomized clinical trials involving patients with proven lung cancer, with analysis of morbidity and mortality for RATS and OTS, excluding reviews with sample sizes less than 20. A total of five studies, five of which reviewed morbidity, while three reviewed mortality, were ultimately selected to be included in the meta-analysis (Zhang & Gao, 2015).

Relative risk (RR) was compared between the two approaches. When comparing morbidity, RATS was shown to have a lower risk than OTS (0.75 vs 0.92, $P<0.01$). In the three studies selected that compare mortality between the two approaches, RATS was also shown to have a lower risk (0.03 vs 0.59, $P = 0.007$) (Zhang & Gao, 2015).

Cost Analysis

Two cost analyses were reviewed. The first created an estimated minimum cost for each surgical case utilizing a robotic surgery platform, and the second analyzes the feasibility of performing robotic thoracic surgery in the setting of a cost-controlled national healthcare plan.

Estimation of the Acquisition and Operating Costs for Robotic Surgery (Childers & Maggard-Gibbons, 2018)

This article endeavored to create a benchmark to help understand the cost of acquisition and maintenance for robotic surgical systems, and to establish a minimum cost a hospital should expect to spend when acquiring a robotic surgical system (Childers & Maggard-Gibbons, 2018). As a financial analysis based on statements of a single medical device company, without any analysis of patient or surgical outcomes, this article provides a level of evidence of VI.

This benchmark was created using the financial statements, Form 10-K annual reports, of Intuitive Surgical Inc, the manufacturer of the Da Vinci robotic surgery platform, collected from January of 1999 through December 2010. The cost of the robotic systems themselves, along with the maintenance and training contracts, and instruments and accessories were taken into account. The costs incurred by the hospital were divided by the number of cases performed to create a theoretical minimum cost (Childers & Maggard-Gibbons, 2018).

Globally, 877,000 robotic procedures of all types were performed in 2017; Intuitive earned $3.1 billion during that same year. That year $1,636,900,000 (52%) of Intuitive's income came from instruments and accessories, $910,200,000 (29%) from the robots themselves, and $581,800,000 (19%) from the service and education contracts. This equates to a cost of $3568 per procedure, with $1866 for instruments, $1038 for the robot platform, and $663 for the service contract, all of which is above and beyond the standard operating room costs, providers' fees, and any other expenses incurred by the patient during a hospital stay. Though many surgeries require the use of disposable instruments, the majority of surgical equipment is relatively cheap, and re-usable. Robotic surgery places additional cost burden on hospital systems by requiring payment for the robot itself, a cost not replicated in other surgical approaches, and by requiring expensive disposable equipment that may only be used a set number of times (Childers & Maggard-Gibbons, 2018).

Cost-Benefit Performance Simulation of Robot-Assisted Thoracic Surgery as Required for Financial Viability under the 2016 Revised Reimbursement Paradigm of the Japanese National Health Insurance System (Kajiwara et al., 2018)

This cost-benefit analysis was performed by Dr Kajiwara and his colleagues from the Tokyo Medical University to create a medical fee system for RATS that fits within the Japanese National Health Insurance System (JNHIS) (Kajiwara et al., 2018). As a strictly financial analysis without an analysis of patient or surgical outcomes, this study has a level of evidence of VI.

The JNHIS covers the entirety of Japan, requiring that patients pay a fixed 30% of any medical expenses, while the remainder is paid by the government. In the last decade, robot assisted laparoscopic prostatectomy (RALP), and robot assisted partial nephrectomy (RAPN) have both been approved for reimbursement by the JNHIS for $5420 and $3485 respectively, and there is interest amongst thoracic surgeons to expand this coverage to robotic lobectomies (Kajiwara et al., 2018).

In 2015 a preliminary study was performed by the same working group to assess the cost-benefit performance of RATS compared to video assisted thoracoscopic surgery (VATS) to establish their own surgical technique for performing RATS and to accurately assess its economic impact. In that study 20 cases of mediastinal and chest wall tumors, and lung cancer were treated robotically to establish the cost of RATS. At this time, the researchers determined the additional cost of robotic surgery compared to VATS, provided 100 cases be done per year, to be $6700 for benign tumors, and $4355 for malignant tumors (Kajiwara et al., 2015).

The focus of this study was to assess the ultimate cost for each RATS lobectomy and to understand how many would need to be performed per year in order for the procedure cost to come near precedents set by the reimbursement prices for RALP or RAPN. Their cost-estimate is dependent on the number of cases that each machine would be utilized for each year. In this scenario, the cost of the machine, $2,232,000, and the maintenance fee, $86,300/year, would be divided by the number of cases performed, plus the fixed cost of the disposable materials expended per case, $1608. When performing 100 cases, the end cost would be unacceptably high when compared to existing reimbursement rates for robotic surgery, at $6850 per operation. The same calculation is performed on the assumption of 150, 200, and 300 cases per year, coming to $5103, $4229, and $3355 per case respectively. In order for RATS lobectomies to be cost neutral while receiving similar reimbursement as RALP ($5420), at least 150 procedures would need be performed per year per machine. If the standard set by RAPN for reimbursement ($3485) was applied to RATS, at least 300 RATS cases would need be performed per year per machine to avoid incurring a cost (Kajiwara et al., 2018).

Body

Resection of non-metastasized lung tumors has proven long-term survival benefits and as such surgical resection remains the ideal treatment for patients with stage I or II non-small cell lung cancer (NSCLC). Those with stage IIIa may receive chemotherapy and/or radiation treatments prior to undergoing surgery, while for those with stage IIIb or IV lung cancer, surgery is not an option. The open approach to thoracic surgery is performed via a lateral or posterolateral thoracotomy incision with the patient in the lateral decubitus position. The underlying muscles are divided, as are the intercostal muscles and the pleural cavity is entered, providing exposure of the pulmonary hilum, the area of the lung where the arteries, veins, bronchi, and nerves enter and leave the lung. Following dissection and excision of the target lobe or section, chest tubes attached to water seal or suction are placed, and the incision is closed. The most common complications seen with the open approach are dysrhythmias, deep vein thrombosis, pulmonary embolism, myocardial infarction, acute respiratory distress syndrome, fistula formation, and damage to the recurrent laryngeal or phrenic nerves (Barash, 2017). As the research shows, the incidence of any of these complications is higher in the open approach that by either minimally invasive approach.

The video assisted thoracoscopic surgical (VATS) approach is used to perform multiple diagnostic and therapeutic procedures including diagnosis of recurrent pneumothoraxes, lung biopsies, lobectomies or segmental resections, pleural effusions, resection of bronchogenic and mediastinal cysts, and pneumonectomies. It is performed under general anesthesia using a double-lumen tube to establish one-lung ventilation. Carbon dioxide insufflation may be used to provide additional space within the thorax by displacing the diaphragm caudally. The techniques and equipment used vary by surgical center. Generally, the patient is placed in the lateral decubitus position, and two to four 0.5 to 1.2cm port incisions are made in a triangular configuration with the center of the triangle over the area of interest. These port incisions allow introduction of the fiberoptic thoracoscope, usually through the most inferior port, and instruments. Often along with a larger (≈4cm) utility incision. Port placement is also dependent on the procedure being performed and the lobe being operated on. The chest cavity, pleura, hilum, mediastinum, and diaphragm are displayed on the video monitor and can each be directly inspected by manipulation of the thoracoscope. Each port site may be alternatively used for retraction, dissection, and visualization. VATS has been shown to be the preferred method for patients with cardiopulmonary compromise, poor performance, poor pulmonary function tests, advanced age, and other comorbidities that could complicate recovery following open thoracic surgery (Merritt, 2015). Of note, the Cancer and Leukemia Group B, an American cancer research group, defines a “true” VATS lobectomy as using only one 4-8cm incision with up to three 0.5cm port incisions and without the use of a rib spreader or retractor (Cao et al., 2014).

For a RATS approach, the initial set-up is similar to VATS, though a variety of techniques have been developed since the introduction of robotic thoracic surgery, one of the first techniques is described here. The intrathoracic space is first visualized with a conventional throacoscope to verify tumor location and assess for the resectability of the tumor, through a port placed at the posterior axillary line. A second incision is made above the diaphragm and behind the tip of the scapula for the purpose of retraction. A utility incision is made at the midaxillary line, at varying intercostal levels depending on the lobe of interest. At this point, the conventional VATS instruments are removed, and the robot is moved next to the patient. The camera is attached to the camera arm and inserted through the camera port into the patient, and additional instruments are guided in under thoracoscopic observation. At this point, the surgeon leaves the patients side and uses the robot’s control console to complete the remainder of the procedure .The surgical technique itself is similar to the VATS technique, with the primary difference that the robotic arm mounted videoscope and instruments are controlled by the surgeon sitting at a console, manipulated by hand controls and foot pedals (Park, Flores, & Rusch, 2006).

The purported benefits of robotic surgery are derived primarily from the advanced technology packaged in each platform. The da Vinci surgical system, manufactured by Intuitive Surgical, incorporates the Insite ® vision system, which provides a 3-dimensional, high resolution, binocular view to the operator, which is reported to be superior to both VATS and open procedures. It also uses the proprietary EndoWrist® instrument system, giving the operator 7 degrees of movement and 2 degrees of axial rotation. These systems work in tangent to potentially provide a distinct advantage over the straight, non-articulated devices used in VATS procedures (Park et al., 2006). Recent improvements include physiologic tremor filter, preventing small movements by the operator's hands from inadvertently moving the instruments, and advances have been made in the most recent da Vinci model to prevent unintended collision of the robot's arms with each other or the patient.

The retrospective database reviews show similar statistically significant outcomes when comparing RATS lobectomies and resections to the same surgeries performed via VATS. Length of stay was shown to be shorter for RATS surgeries in the studies by Kent and Oh, and shorter for VATS in the studies by Paul. The studies that reported operating room time showed longer duration for robotic surgeries. In the studies by Kent and Oh, mortality was shown to be lower for robotic surgery. Patients undergoing RATS were shown to be more likely to be discharged home in the studies by Paul and Oh. Kent et al.'s study showed additional decreases in morbidity and mortality when robotic surgery is performed by a surgeon performing more than 20 cases a year. In Oh et al.'s study, RATS was compared to open lobectomies, and was shown to have longer operating room times, similar intraoperative complication rates, lower postoperative complication rates, lower 30-day postoperative complications, and lower postoperative and 30-day mortality. Conversion from RATS to open thoracotomy was also seen to be less likely in Oh et al.'s study when compared to VATS.

The database-driven studies including oncological outcomes had similar findings. Both studies by Louie et al, and Yang et al showed longer operative times for robotic surgery, and similar complication rates between all three approaches. Both studies showed shorter length of stay. In terms of nodal upstaging, Louie et al.'s study showed similar rates between robotic and video assisted approaches, while the study by Yang et al. showed a non-significant increase in nodal upstaging and a significant increase in lymph node stations sampled for the robotic approach. Overall survival and disease-free survival, following multivariate analysis were shown to be the same for all approaches.

In the small-scale, single center retrospective studies outcomes similar to the multicenter retrospective analyses were seen. Operating room time was shown to be longer for robotic surgery in all studies, while length of stay was shown to be similar to VATS or shorter. Morbidity and mortality were similar for the two approaches. When economic impact was analyzed, cost was shown to be higher for robotic surgery than other approaches. The stated intent of these studies was to look for equivalency between the VATS program their institutions had been using and the new robotic programs they were instituting. These studies showed RATS provided similar outcomes, without showing explicit superiority in any metric when compared to VATS.

The meta-analyses reviewed showed decreased morbidity and mortality when comparing RATS to either VATS or open thoracotomy. Agzarian et al.'s study showed longer operating room time, higher costs, and a non-significant increase in lymph node stations dissected. Zhang & Gao's analysis looked only at the difference in morbidity and mortality for RATS compared to open approach showed superiority for RATS in both areas.

The financial analyses set a minimum cost for robotic surgery of any description and determined the minimum number of robotic thoracic surgeries that would need be performed in a given year in order to avoid incurring debt.

Discussion

This review makes clear three truths about robotic and nonrobotic thoracic surgery. The first is that when compared to either minimally-invasive approach, open thoracic surgery is the inferior choice. Risk of morbidity and mortality, complication rates, length of stay, and pain are all increased with the open approach. Many still prefer the open approach, especially for lobectomies, and in a survey of thoracic surgeons performing lobectomies only via the open approach, the primary concerns with minimally invasive approaches were lack of experience and exposure, and concerns regarding oncological efficacy. Additionally, both thoracoscopic techniques are contraindicated in tumors involving the ribs, and for patients with a forced expiratory volume in the first second (FEV_1) of <30% or diffusing capacity of the lungs for carbon monoxide (DLCO) <30%, rendering open lobectomy the only choice in these cases (Cao et al., 2014).

The second truth revealed is that when comparing robotic and video assisted thoracoscopic surgery, a clear superiority of one modality does not yet exist. Both methods show similar intraoperative and postoperative outcomes, both have steep learning curves but have shown improved efficiency with provider practice and repetition, and both methods have been shown to have similar oncological outcomes, though the RATS approach may show a slight advantage.

The final fact made clear in this review is that robotic surgery is expensive, adding several thousand dollars to the cost of every procedure, and tens of thousands of dollars to a department’s overhead every year.

This raises the question: if robotic thoracic surgery is only equivocally superior to video-assisted thoracic surgery, what place does robotic assisted thoracic surgery have, given its increased cost? The VATS approach was initially described in the early 1990s, but the majority of thoracic surgeries examined in this review are still performed via the open approach (Oh, Reddy, Gorrepati, Mehendale, & Reed, 2017). This is reportedly due to the inherent difficulty of the VATS approach, due to its two-dimensional view and nonergonomic instruments (Mungo et al., 2016). Rather than comparing RATS with VATS and looking for a clear advantage, we need to think of the robot as the next iteration of VATS technology as opposed to an expensive alternative and consider the direct patient advantage of the minimally invasive approaches. The focus should be on decreasing the number of open approaches by funneling those patients with tumors deemed too deep or complex for VATS, into robotic surgery, taking full advantage of the platform's abilities and using the open approach as a last resort.

To that end, further research is required. As of the writing of this review, no randomized control studies comparing robotic, video-assisted, and open thoracic surgery have been performed, providing only low levels of evidence to recommend the robotic approach over another. In 2016, an Australian randomized control study comparing robotic and radical prostatectomy showed a clear advantage for the robotic approach for operating room time, outcomes, blood loss, length of stay, and number of positive lymph nodes dissected. Though the study was small, with 308 patients randomized between two surgeons, one performing radical and the other robotic prostatectomies (Yaxley et al., 2016), it provides an excellent framework for comparing robotic and open thoracic surgery. A randomized control study that shows improved patient outcomes and similar or improved rates of nodal upstaging and lymph node dissection for RATS compared to open surgery could justify and encourage further utilization of robotic surgery.

High cost is the primary drawback for robotic surgery but could be mediated in two ways. The first is limiting robotic platforms to high volume institutions. A significant enough number of cases can be performed to offset the increased cost to the hospital, over 150/year per Dr. Kajiwara's study, and the surgeon, operating room staff, recovery area, and intensive care unit will become more efficient and effective, decreasing operative time, recovery time, and length of stay to decrease costs to the patient.

The other way to control costs for robotic surgery is through competition. From its inception, robotic surgery has been almost universally performed using iterant generations of the da Vinci platform by Intuitive Surgical, creating a monopoly with little incentive to control costs. Multiple new platforms have been developed in recent years, providing potential advantages over the da Vinci, including haptic feedback, pupil tracking, and more to the point at hand, reusable instruments and lower costs. While most of these platforms are in the nascent stages, and even the most developed have seen only limited clinical use, their presence should induce the industry leader to begin controlling costs (Peters, Armijo, Krause, Choudhury, & Oleynikov, 2018).

Robotic surgical platforms will continue to see increased deployment in many surgical fields as new technology is developed and approved. It is prudent that the educated anesthetist understands the purported and proven benefits of any new technology being brought into the operating room and examines any large investment with a critical eye towards the actual benefits being provided to the patient.

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